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Second Annual Progress Report

July 1, 1961 - October 31, 1962

Principal Investigator - Sid Robinson

Indiana University Foundation
Research Division
Bloomington, Indiana

Title: THE PHYSIOLOGY OF SWEAT GLANDS

Supported by Grant No. DA-MEDDH - 60-10

U.S. Army Medical Research and Development Command
Department of the Army
Washington 25, D. C.

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We have studied the time relations of the sweating responses of men during vigorous exercise and recovery with corresponding changes of temperature in the rectum, oesophagus, tympanic membrane, femoral and saphenous veins, gastrocnemius muscle and at 7 points on the skin. The results suggest that sweating was regulated in these exercise experiments by reflex effects originating from thermal receptors in the veins which drain warm blood from the working muscles, summated with reflexes from cutaneous thermal receptors, and with alterations of activity if the hypothalamic center produced directly by temperature changes in the center. Mechanoreceptors in muscles and joints probably do not participate in the regulation of sweating in exercise. Evidence for this is that when men were exercised passively on a motor driven bicycle in a warm room (34°C.) sweating was increased only in proportion to the increments of metabolism and muscle temperature produced by the passive exercise. d-Aldosterone, administered to normal men by continuous intravenous infusion, was found not to alter the NaCl concentration of their sweat during 5 to 7-hour periods of work in the heat (45°C.). Continuous infusion of d-aldosterone at 0.1 mg/hr into one brachial artery did not alter the Na or Cl concentration of sweat being secreted by the infused forearm, either from simultaneously collected samples from the man's other arm, or from control values in both arms before the infusion was started. It is planned to continue the work by investigations of the effect of d-aldosterone on the sweat concentrations of patients with abnormal adrenocortical function. Arrangements have been made to study the effects of age on the ability of men to acclimatize to work in hot environments. The same subjects used in our acclimatization study in 1942 (Am. J. Physiol. 140:168, 1943) will be reacclimatized to the same conditions and their responses compared with their responses in the former study.

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Second Annual Progress Report

July 1, 1961 - October 31, 1962

The Physiology of Sweat Glands

Object: To study the basic mechanisms of sweat gland function, including both endocrine and nervous regulatory influences on the secretion and on the composition of sweat.

Period:

The terminal date of the grant was extended from July 1, 1962 to October 31, 1962. Therefore the present report will cover the period July 1, 1961 to October 31, 1962. The grant was renewed for a year beginning November 1, 1962 as: MEDDH-SP, Grant No. DA-MD-49-193-63-G91.

Progress during the first year of this research was outlined in our First Annual Progress Report, Grant No. DA-MEDDH-60-10, July 1, 1960 to June 30, 1961, by Sid Robinson

Personnel:

Principal Investigator, Sid Robinson; Research Associate: R. S. Roof, M.D.; Research Assistant: J. L. Newton; Part-time Assistants: T. P. McConahay, F. R. Meyer, C. Ts'ao; Technician, R. R. Zink.

Results:

During the second year of this research two papers were presented at the 1962 Autumn Meeting of the American Physiological Society and two other manuscripts have been prepared and will be presented at the 47th Meeting of the Federation of American Societies for Experimental Biology, April 1963.

THE REGULATION OF THE SWEATING RESPONSE TO WORK IN MAN. F. R. Meyer, S. Robinson, J. L. Newton, C.H. Ts'ao, and L. O. Holgersen, The Physiologist 5: August 1962.

A study was made of the time relations of the sweating responses of men in exercise with corresponding changes of temperature at various locations in the body. A series of 50-minute treadmill work experiments was carried out on men in which sweating was determined at frequent intervals by net weight loss, and temperature was recorded by thermocouples in the femoral vein, long saphenous vein,

gastrocnemius muscle, rectum, esophagus, tympanum, and at 7 points on the skin. When the intensity of work was varied from experiment to experiment and room temperature held constant (25°C), the acceleration of sweating and the steady state attained during work, as well as the decline of sweating following work are all more closely related to changes of temperature in the working muscles and in the femoral veins draining blood from the leg muscles than to temperature changes in any of the other locations studied. When work was constant (4.5mph/9% grade) and the environmental temperature varied from experiment to experiment (15, 25, 34, 40°C), mean skin temperature varied with the environmental temperature, but the rectal, femoral vein, and muscle temperature were about the same in all of the 3 cooler environments. In this series sweating increased with the increments in skin and environmental temperature without corresponding changes in the deep body temperatures. Results suggest that sweating was regulated in these experiments by reflex effects originating from thermal receptors in the working muscle or in the veins draining the muscles, summated with reflexes originating from cutaneous thermal receptors, both acting through the hypothalamic center, the excitability of which was increased in proportion to its own temperature. (Supported by the U. S. Army Medical Research & Dev. Command Grant DA-MEDDH-60-10.)

2. UREA TRANSFER ACROSS THE SWEAT GLANDS. G. K. Komives, S. Robinson, F. R. Meyer, C. H. Ts'ao, and J. T. Roberts, The Physiologist 5: August 1962.

The effects of varying the plasma urea level and the rate of sweating on the concentration of urea in the sweat were studied on men walking on a motor-driven treadmill in a hot, dry environment in which sweat evaporated from the men as it was formed. Hourly sweat rates were measured as the net weight losses of the men, and analyses were made of the sweat residue washed from the skin at the end of each hour with a measured volume of distilled water. This method makes possible the collection of sweat from the whole body under normal physiological conditions. When plasma urea was raised 4-fold (150 mg%) by the ingestion of urea, the urea level of the sweat always remained the same as that of the plasma. The sweat and plasma concentrations also remained the same despite an almost 2-fold variation in the sweat rate. This relation was unaffected during adaptation of the men to salt deficiency in which the sweat glands were forced to increase their osmotic work. These results were interpreted to mean that sweat urea arises from the extracellular fluid by a process of passive diffusion across the sweat glands. Since the

urea level in the plasma and sweat were the same, it was concluded that when the skin is functioning under normal atmospheric conditions the amount of urea cleared by the sweat glands depends entirely upon the sweat rate. In one series of experiments, the kidney urea clearance was $45 \text{ ml}/1.73 \text{ m}^2/\text{min}$ while that of the sweat glands was $17 \text{ ml}/1.73 \text{ m}^2/\text{min}$ at a sweat rate of $15 \text{ ml}/1.73 \text{ m}^2/\text{min}$. (Supported by U. S. Army Medical Research and Development Command, Grant DA-MEDDH-60-10.)

3. VARIATIONS OF LACTATE IN SWEAT. J. T. Roberts, Beatrice Epperson, and G. Komives, Federation Proceedings 22: (in press), 1963.

Men worked on a treadmill (3.5 mph, 2.5% gr) in the heat (45°C d.b.; 25°C w.b.) for periods of 3 to 5 hours. Hourly sweat rates determined by net weight loss averaged $0.7 \text{ kg}/\text{m}^2/\text{hr}$. During continuous exposure sweat chloride concentration generally increased with time while lactate decreased. There were no changes in sweat lactate concentration associated with large reductions in sweat chloride concentration during several days of salt depletion in which the osmotic gradient was increased. Sweat lactate concentration varied inversely with sweat rates ranging from 0.4 to $0.85 \text{ kg}/\text{m}^2/\text{hr}$, while the total hourly output of lactate remained constant. Sweat lactate was independent of blood lactate. Increasing the blood lactate level from 5 to 100 mg% by exhausting exercise in the heat caused no rise in sweat lactate. Men experiencing dehydration, up to 2.5 kg, showed lower sweat lactate concentrations than during similar experiments in the hydrated state. Decreasing the blood flow to the skin during exposure by administration of Pitressin did not significantly alter sweat rate or sweat lactate concentration. (Supported by a grant from U. S. Army Medical Research and Development Command. No. DA-MEDDH-60-10.)

d-ALDOSTERONE AND SWEAT ELECTROLYTES. J. L. Newton, S. Robinson and T. P. McConahay, Federation Proceedings 22: (in press), 1963.

Men worked (MR 190 Cal/m²/hr) in the heat (45 C d.b.; 25 C w.b.) for periods of 5 to 7 hours, maintaining water and salt balance by drinking appropriate saline solutions. Hourly sweat rates determined by net weight loss averaged 0.7 kg/m²/hr. d-Aldosterone was administered by continuous intravenous infusion at 0.1 mg/hr during the 3rd to 7th hours without altering the Na or Cl concentration of the men's sweat from control values determined during the first two hours of the exposures, or from values observed during separate control experiments. Na and Cl concentrations of sweat secreted the day following the infusion experiments were not significantly different from samples collected the day after control experiments. The salt conserving responses of the men's sweat glands 7 to 24 hours following salt depletion (-160 to -240 mEq) were not significantly altered by infusions of 0.5 to 1.2 mg of d-aldosterone. Continuous infusion of d-aldosterone at 0.1 mg/hr into one brachial artery did not alter the Na or Cl concentration of sweat being secreted by the infused arm, either from simultaneously collected samples from the man's other arm, or from control values in both arms before the infusion was started. (Supported by a grant from U. S. Army Medical Research and Development Command. No. DA-MEDDH-60-10.)

Another project has been completed and a manuscript is being prepared for publication:

NEUROMUSCULAR ELEMENTS IN THE REGULATION OF SWEATING.

L. D. Holgerson, S. Robinson, F. R. Meyer and C. H. Ts'ao (in preparation).

The purpose of this study was to determine whether or not reflexes originating from mechanoreceptors in muscles and joints may participate in the regulation of sweating in men during work.

The legs and arms of young men were exercised passively on a motor driven bicycle ergometer, operating the pedals at 60 cycles/min. Some experiments were performed at a room temperature of 28°C and others at 34°C with low relative humidity to facilitate evaporation. Measurements were made of metabolism, of skin, rectal and muscle (gastrocnemius) temperature, and of sweat rate. Observations were made during a 1-hour control period and continued through a 40-minute period of passive exercise, followed by one hour of recovery. Results of the experiments are summarized in Table 1.

Table 1. Average values on 3 subjects in experiments performed at two different environmental temperatures.

	Room Temp. 28°C.		Room Temp. 34°C.	
	Rest	Passive ex.	Rest	Passive ex.
O ₂ cons. cc/min.	254	400	255	417
Gastr. Temp. °C.	33.7	34.6	35.1	36.0
Rectal Temp. °C.	37.4	37.3	37.3	37.5
Av. Skin T. °C.	33.2	33.2	35.3	35.4
Wt. loss g/hr.	42	66	96	186

Metabolism was increased an average of 60% during the period of passive exercise. Gastrocnemius muscle temperature rose an average of 0.9°C, during the passive exercise period and declined rapidly during recovery. Rectal temperature rose very slowly an average of 0.2°C during the exercise and continued to rise slightly during recovery for periods up to 20 minutes, long after sweating and muscle temperature had returned to control levels. Skin temperature was higher in the warmer environment, but was not significantly altered from control values during passive exercise in either environment. In a room temperature of 28°C insensible weight loss rose from 42 g/hr in rest on the bicycle to 66 g/hr during passive exercise. In the warmer environment (34°C) frank sweating occurred during passive exercise and weight loss was 93% greater than in rest corresponding with a 64% increase of O₂ consumption.

The correlation between the increments of weight loss and gastrocnemius muscle temperature during the period of passive exercise, and the fact that in a particular environment the changes in sweating were not dependent on changes in either skin or rectal temperature, suggest the possibility that thermal receptors in the muscles themselves may participate reflexly in the regulation of sweating during exercise. Data of Meyer, et al, in the first paper above suggest that possible thermoreceptors in the veins draining blood from the muscles may be involved. The increments of sweating and skin temperature with environmental temperature indicate that reflexes from cutaneous thermal receptors serve also to excite the sweating response. The data lend no support to the idea that mechanoreceptors may be involved.

MICROPUNCTURE COLLECTION AND ANALYSIS OF SWEAT
FROM HUMAN ECCRINE SWEAT GLAND AND DUCT. R. S.
Roof, (in preparation).

Adapting micropuncture methods to the human eccrine sweat gland involves overcoming three major obstacles, (1) With normal lighting it is not possible to see to adequate depth through human skin to carry out micropuncture of the proximal zone of the duct of the eccrine sweat gland. (2) The relatively small internal diameter of the duct of the eccrine sweat gland complicates many mechanical aspects of micropuncture. (The internal diameter of the eccrine duct is 1/10 to 1/15 that of the Necturus kidney tubule that is usually used in renal micropuncture work.) (3) The relatively small minute volume output of a single sweat gland requires that collection be extended over a long time period and/or samples be pooled. This requires first placement of the pipetts, followed by immobilization of the pipett at the site. Since the work is being done in the human rather than an immobile anesthetized animal, immobilization of the pipett creates an additional mechanical problem.

On the first obstacle the following methods have been explored. (1) Tape, colloidin and microdissection stripping of epidermis. (2) Clearing the epidermis with oils and other agents. Using these agents at the epidermal surface, injecting agents at the epidermal-dermal junction and by surface chambers. (3) Transillumination by subcutaneous fused quartz rod. (4) A wide variety of filters of different color and intensity have been tested and one found which considerably improves visibility. (5) Differential straining of sweat duct, dermis and sweat by different dyes has been used to increase contrast of the duct. (6) Several types of special light delivery tips have been constructed, arranged so they can be micromanipulated and designed so they provide special condenser functions and these have greatly increased the depth of dermal visualization. (7) The lumen of the duct of the gland has been made visible at greater depths by a semi-darkfield light delivery tip. (8) An intensifying device has improved visualization. (9) A subcutaneous micro light probe has been used. (10) Ultra violet fluorescent methods have been tested. (11) Microdissection exposure of the gland has been explored.

Through a combination of the above methods the first obstacle has been sufficiently reduced so that work on puncture techniques is proceeding.

The program of research is being continued (November 1, 1962 - October 31, 1963) with emphasis on:

1. Endocrine factors in sweat gland function as exhibited in normal men and in patients with abnormal adreno-cortical function.
2. Acclimatization of men to heat in relation to age.
3. Study of the basic physiology of sweat gland function by sampling and analysis of sweat directly from the glands and ducts is being continued with renewed hope of success by Dr. Roger S. Roof.

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